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Olufemi Olowolafe, Robert L. Opila

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University of Delaware
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14. ABSTRACT
We have demonstrated the aqueous growth of ZnO nanorods on a wide variety of substrates including Au, Al, Si, Pt, Ag, ITO, and silica. The rate of nucleation and the form of the crystals depends slightly upon the substrate. Additives can dramatically change the growth habit. The nanorods grow in the (1000) direction and are 0.1 – 10 ?m long. Short, squat rods are appropriate as MEMS actuators, and we are acquiring a nanoindenter to characterize their piezo-electric properties. Long, thin rods may be used as photovoltaic antennae, sensors, or field-effect transistors. We are in the process of testing the conductivity of these crystals by placing the crystal across a metallization pattern and contacting it. The metallization pattern

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Report Title

Nanoscopic ZnO: Growth, Doping and Characterization

ABSTRACT

We have demonstrated the aqueous growth of ZnO nanorods on a wide variety of substrates including Au, Al, Si, Pt, Ag, ITO, and silica. The rate of nucleation and the form of the crystals depends slightly upon the substrate. Additives can dramatically change the growth habit. The nanorods grow in the (1000) direction and are 0.1 – 10 ?m long. Short, squat rods are appropriate as MEMS actuators, and we are acquiring a nanoindenter to characterize their piezo-electric properties. Long, thin rods may be used as photovoltaic antennae, sensors, or field-effect transistors. We are in the process of testing the conductivity of these crystals by placing the crystal across a metallization pattern and contacting it. The metallization pattern provides the capability of making four-point contact. The integrity is ensured by deposition of Pt using a focused ion beam. The surface of the ZnO will be passivated with Si3N4 and SiO2.

List of papers submitted or published that acknowledge ARO support during this reporting period. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Number of Papers published in peer-reviewed journals: 0.00

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Number of Manuscripts:

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Graduate Students

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Names of other research staff

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Sub Contractors (DD882)

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Final Report

Nanoscopic ZnO: Growth, Doping and Characterization

by

Olufemi Olowolafe, Associate Professor,
Department of Electrical and Computer Engineering,
University of Delaware, Newark, DE 19716.
Tel: (302) 831-4272; Fax: (302)831-4316
olowolaf@ee.udel.edu

Robert L. Opila, Professor,
Department of Materials and Engineering,
University of Delaware, Newark, DE 19716.
Tel: (302) 831-3128; Fax: (302)831-4545
opila@udel.edu

A Final Report presented to

US Army Research Office,
Attention: Dr. William V. Lampert,
P.O. Box 12211,
Research Triangle Park,
North Carolina 27709-2211.

Zinc oxide (ZnO) has extraordinary properties as a wide band gap semiconductor, a transparent conductor, a piezoelectric material, and even a magnetic semiconductor. These unique material properties have attracted tremendous interest for various applications, including transparent UV light emitters [1], solar cell applications [2, 3] and, because of its large piezoelectric constant [4], a potential candidate as a micro-electromechanical (MEMS or NEMS) material [5], or in spintronics [6]. As such *ZnO will enhance current military needs such as photovoltaics, radiation-hard and high temperature electronics, and guidance. In addition ZnO will provide opportunity for future military applications such as spintronics.*

Tremendous attention has recently been paid to ZnO nanowires because of novel physical properties and their potential applications in fabricating nanoscale electronic and optoelectronic devices [7]. Recently, Huang et al. demonstrated a UV nanolaser at room temperature using highly-oriented ZnO nanowire arrays [8]. As synthesized, ZnO generally reveals n-type conduction with a typical carrier concentration of $\sim10^{17}/cm^3$, which is smaller than the carrier concentration of $\sim10^{18}$ to $10^{20}/cm^3$ required in a number of applications including laser diode applications. The control of carrier concentration remains a significant challenge. Properly-doped ZnO nanowires will have potential for diverse applications, including microelectronics/nanoelectronics, chemical and biological sensors and diagnosis, energy conversion and storage, light-emitting displays, catalysis, optical storage and drug delivery.

Technical Approach

1. *<u>Synthesis of Nanostructures</u>*

The first device that we have grown includes an array of ZnO nanopillars on metals. Using wet chemical techniques, we have successfully grown clusters of nanopillars on Au, Al, Ti, Si, Pt, and Ag and are currently investigating other substrates including indium tin oxide (see Figure 1 below). The surfaces of the Al, Ti, and Si are presumably oxidized. The wet depositions were carried out using an aqueous equimolar solution of zinc nitrate and hexamethylenetetramine. The nanopillars grow with a (0001) texture as evidenced by their hexagonal structure and their x-ray diffraction pattern.

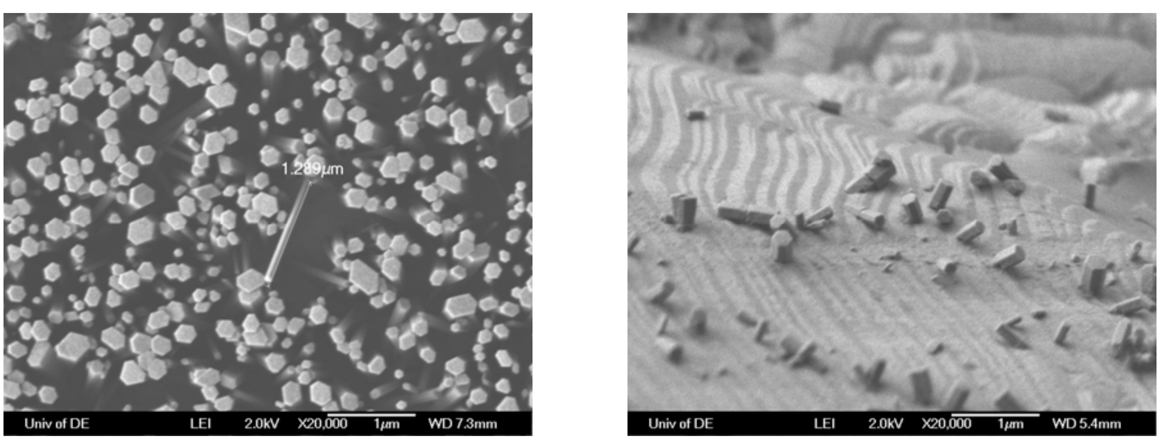

Figure 1. (a) Long, hexagonal structures grown on Ag. (b) Oriented (0001) textured nanorods grown on Pt substrates.

2. *Electrical Characterization of ZnO Nanorods*

We have begun to electrically characterize the conductivity of the nanorods. Our procedure is described below. We expect to be complete in one month (end of September 2007).

1. Grow long ZnO (> 10 μm) nanorods (complete).
2. Design test pattern (shown below), which permits four-point probe of conductivity. We have included redundancy in the mask (there are 6 legs, where four is the minimum required). Mask done and test structure completed.
3. Align the nanorods with the test pattern. The movement is performed using a micromanipulator at the NSF National Nanotechnology Infrastructure Network at Penn State University (in progress).
4. Nanorods will be secured and electrical contact will be additionally ensured by depositing metal contact lines with a focused ion beam (FIB). We have made our first attempts to make electrical contact to one ZnO nanostructure used an FEI Dual Beam FIB. This instrument has a high spatial resolution, liquid metal, ion source, permitting us to measure the electrical properties (initially using a two point measurement). Here we etched small holes, approximately 100 nm, through the SiO_2 layer, using a Ga ion beam. Once the holes were etched, lines were connected to the holes using the interaction of the ion beam with the deposited metal organic Pt compound (in progress).
5. Coat rods with SiO_2 and Si_3N_4 to minimize effects of surface conductivity. The passivations will be deposited using PECVD facility at NNIN PSU. (scheduled)
6. Electrical contact will be made by etching small contact holes through the passivation with H_3PO_4 and HF to the ZnO. This will permit us to make electrical contact to the pads using the micrometer scale electrical tester at the NNIN facility at Penn State.

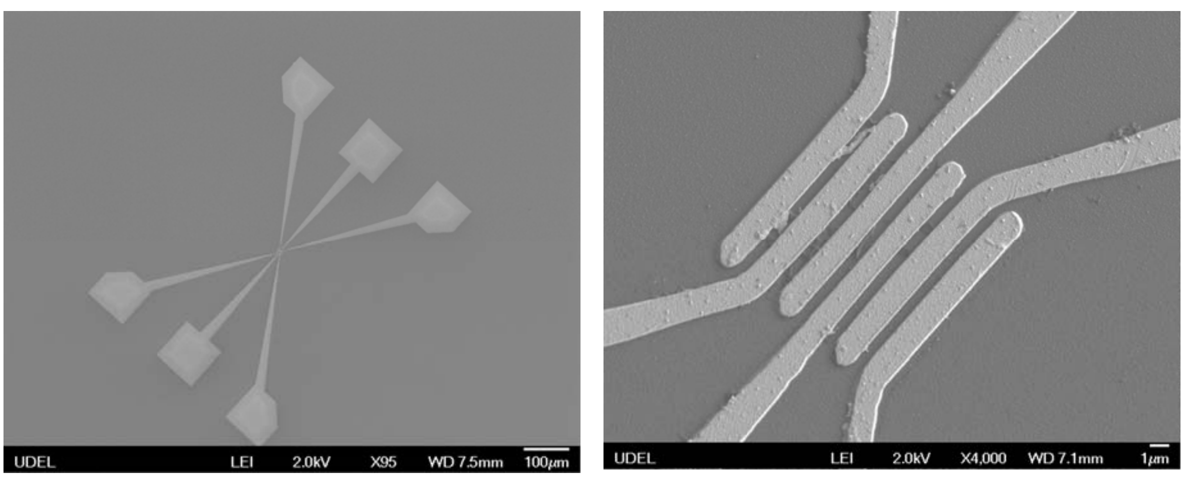

Figure 2. The test pattern to be used for four-point probe of nanorod conductivity.

3. Future work.

1. Doping of nanorods with electrically active *p* or *n* dopants.
2. Doping of nanorods with magnetic dopants for spintronics.

3. Test field effect of conductivity ZnO nanorods.
4. Test piezoelectric effect of ZnO nanorods using Nanoindenter that is being acquired through DURIP for use as MEMS actuator.
5. Test effects of ambient on surface conductivity of ZnO for use as sensor.
6. Develop structure to test photovoltaic effect of ZnO, and develop array of antennae for tuned PV.

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